



Storm Control and Reliability Indexes of Offshore Wind Farms

Cutululis, Nicolaos Antonio

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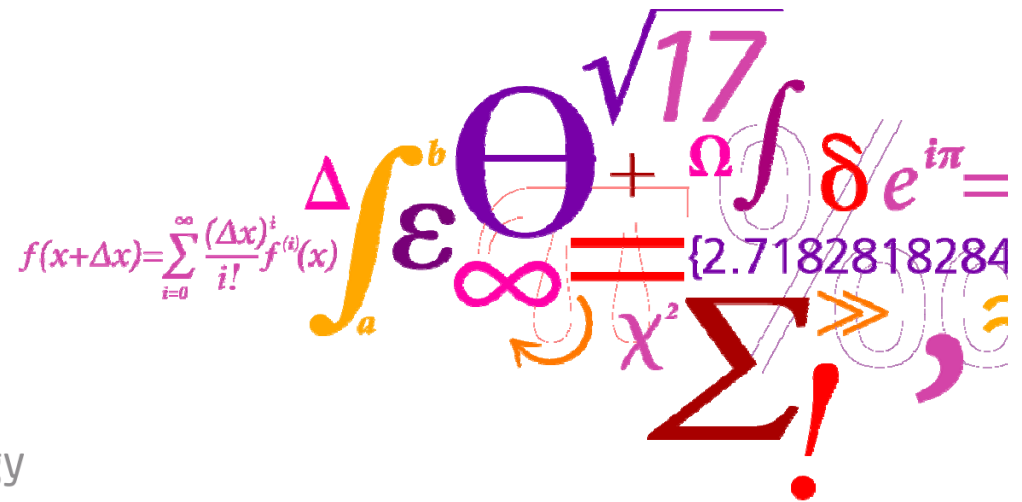
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Storm Control and Reliability Indexes of Offshore Wind Farms

Nicolaos A. Cutululis

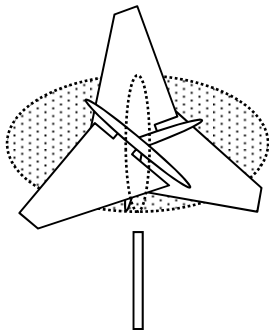


Outline

- Wind power fluctuation model
- Storm control
- Simulation scenarios
- Simulation results
- Conclusions

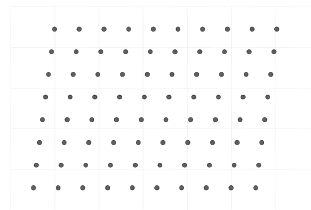
Wind power fluctuation models

2002



Wind turbine(s)

2007



Wind farm

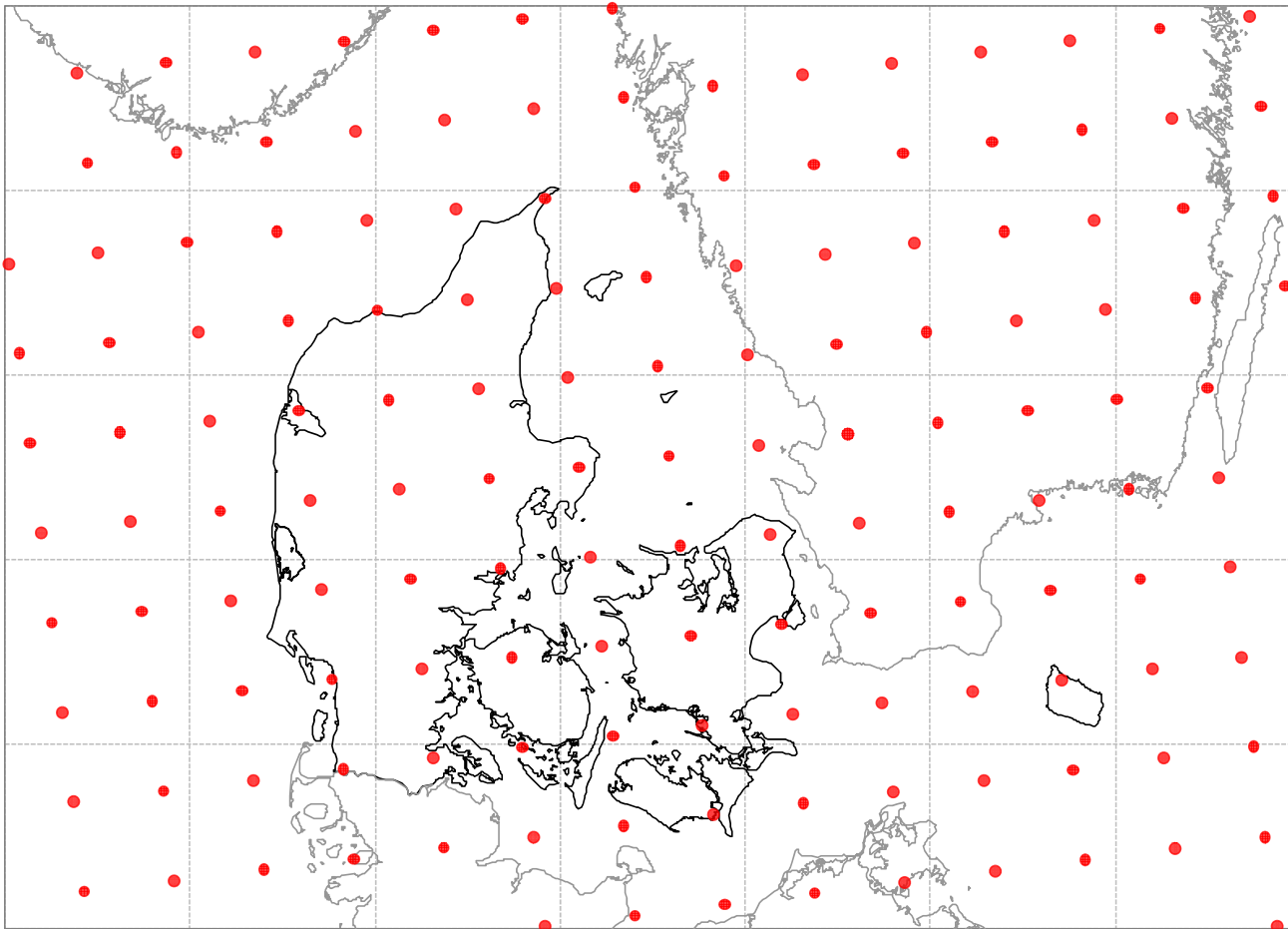
2009



Power system area

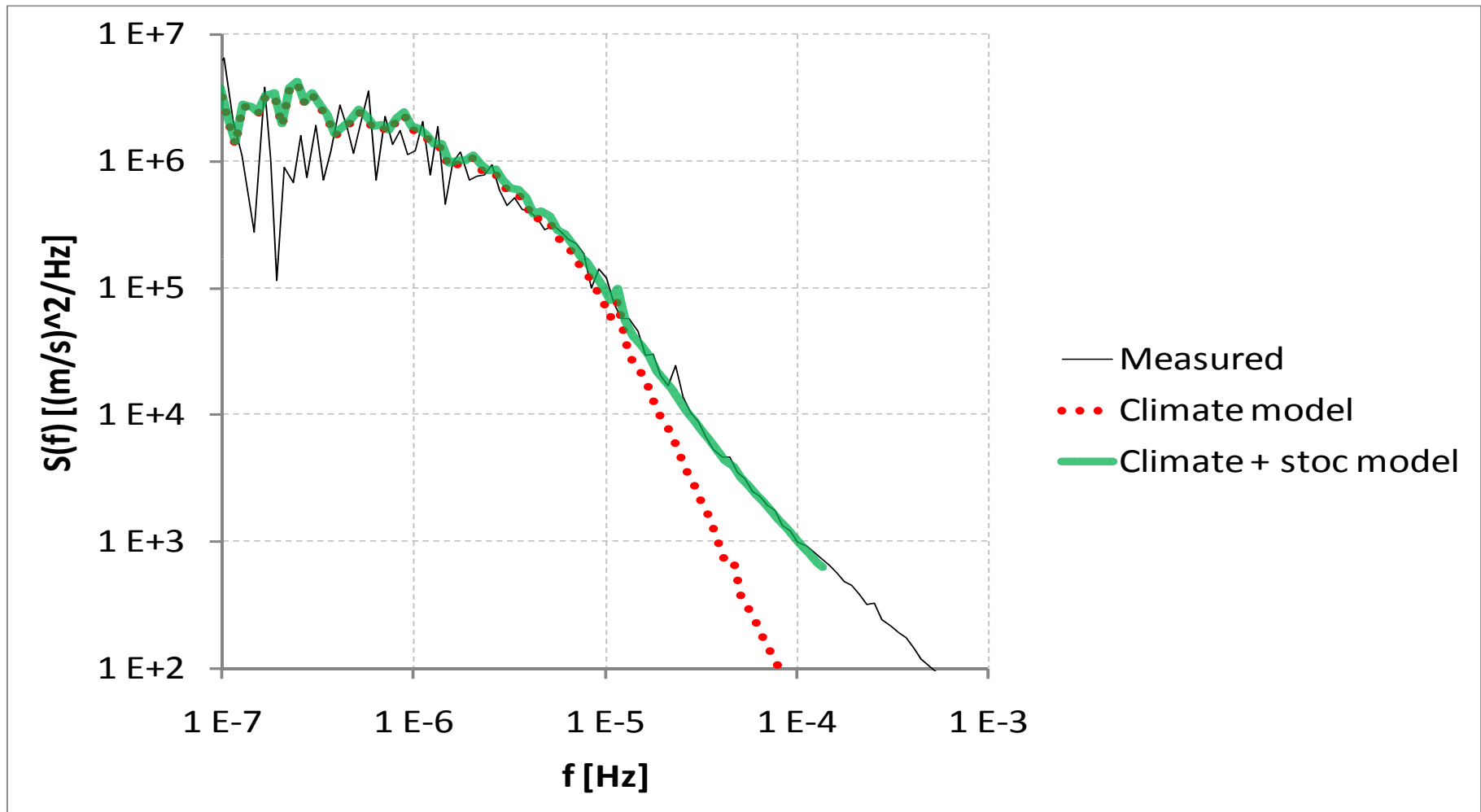
Climate model resolution

Supplied by MaxPlank Germany
25 years of data
1 hour 50 km resolution

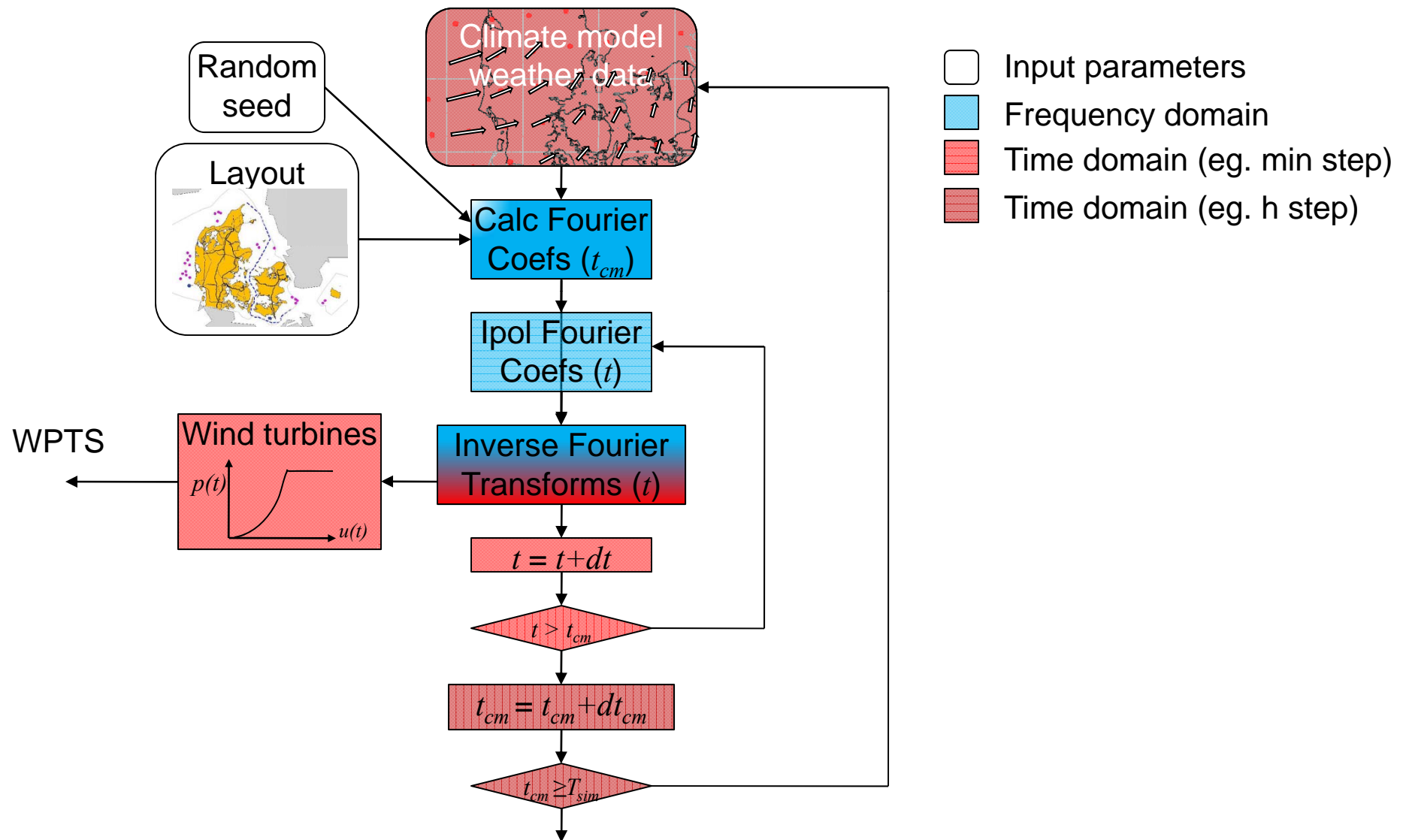


Climate model + stochastic model

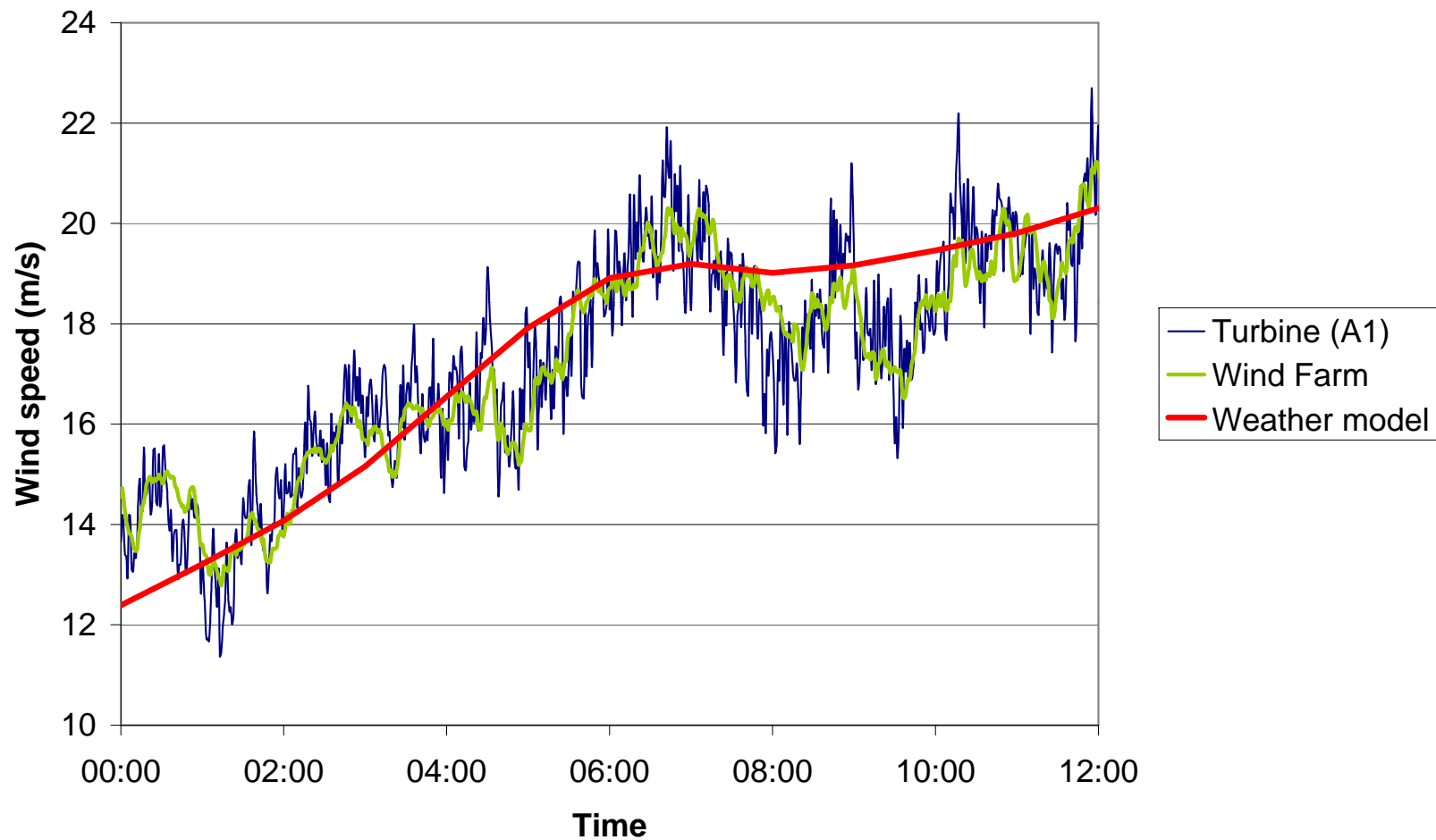
Horns Rev example



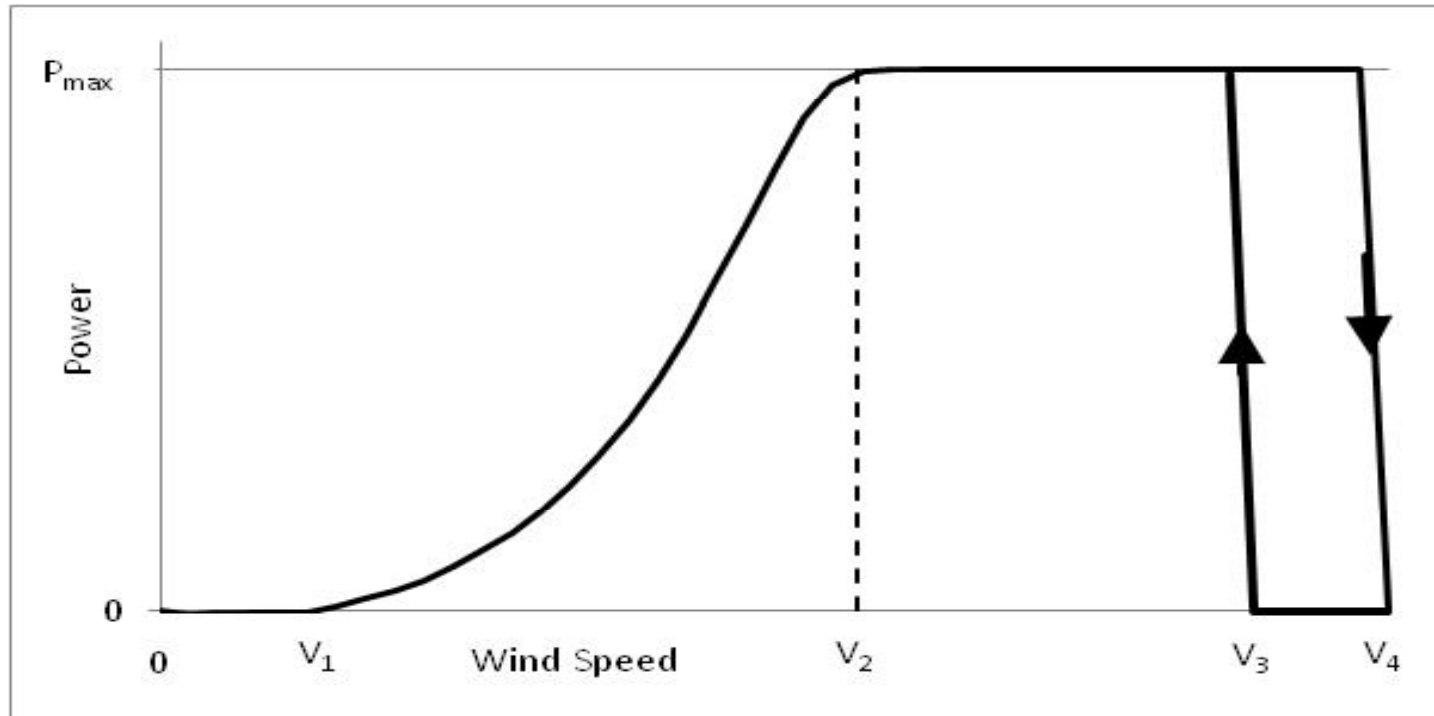
Region wind power model - CorWind



Simulated wind speeds - smoothing

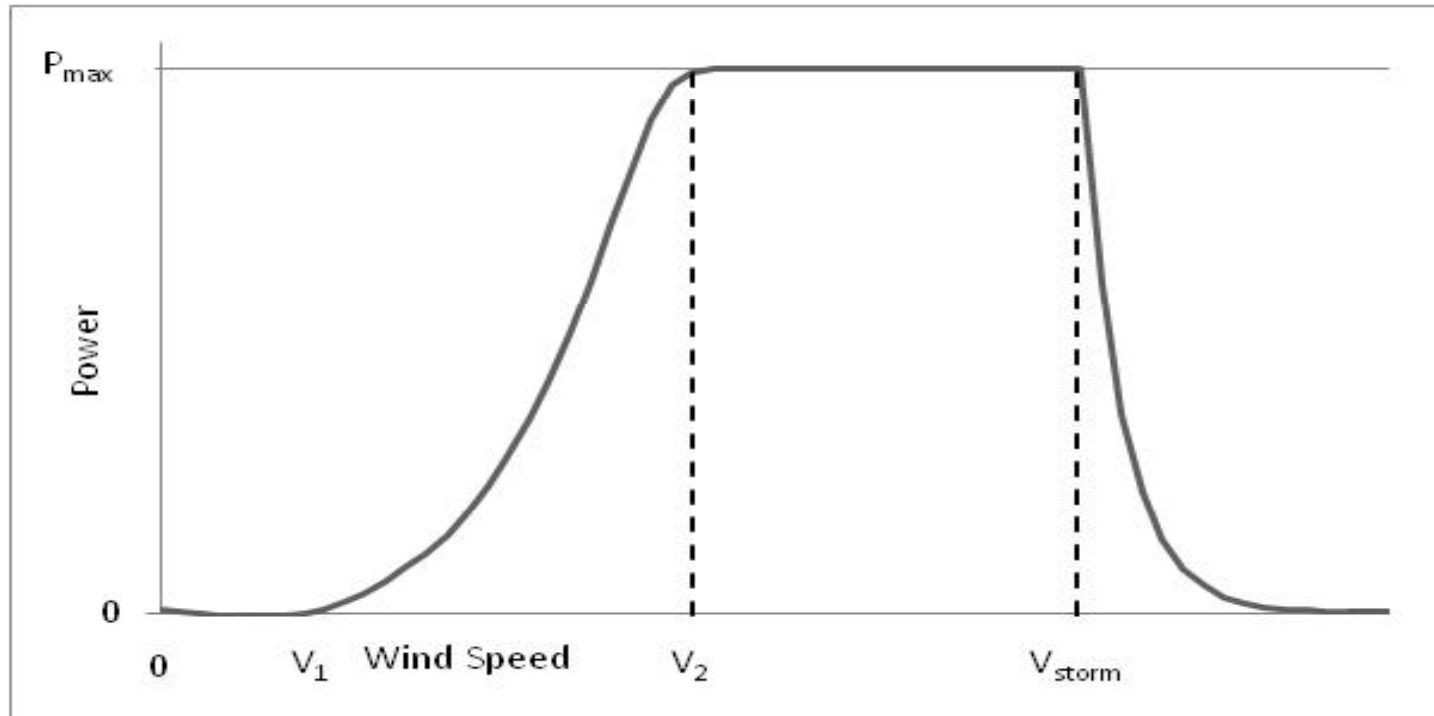


Storm Control



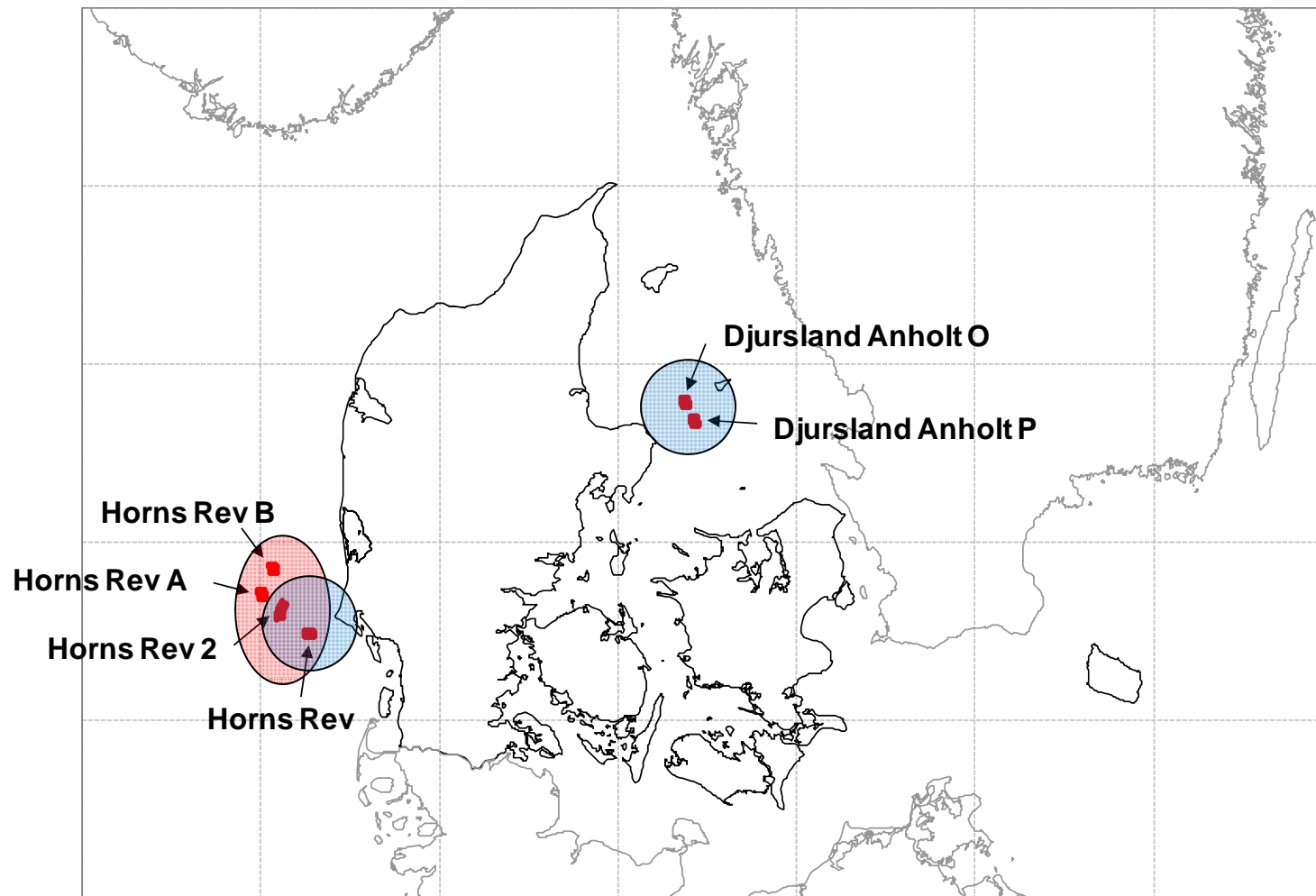
Hysteresis Storm Transition (HST)

Storm Control



Soft Storm Transition (SST)

Simulation cases



Simulation cases

Name	Symbol	Wind turbine power	Total power	Annual mean wind speed
Horns Rev	HR1	80 X 2.0 MW	160 MW	9.6 m/s ^{*)}
Horns Rev 2	HR2	91 X 2.3 MW	209 MW	10.4 m/s ^{*)}
Horns Rev A	HRA	40 X 5.0 MW	200 MW	10.6 m/s ^{*)}
Horns Rev B	HRB	40 X 5.0 MW	200 MW	10.5 m/s ^{*)}
Djursland Anholt O	DAO	40 X 5.0 MW	200 MW	9.0 m/s ^{*)}
Djursland Anholt P	DAP	40 X 5.0 MW	200 MW	9.0 m/s ^{*)}

^{*)}the annual mean wind speeds are assumed, not measured

Simulated 5 years (1999 – 2003) with five different random seeds for the stochastic part – 25 annual wind power time series

Simulation results

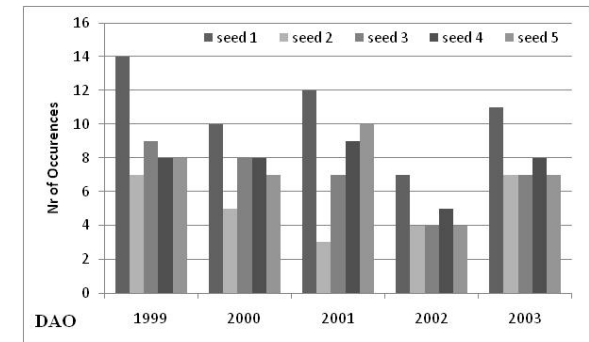
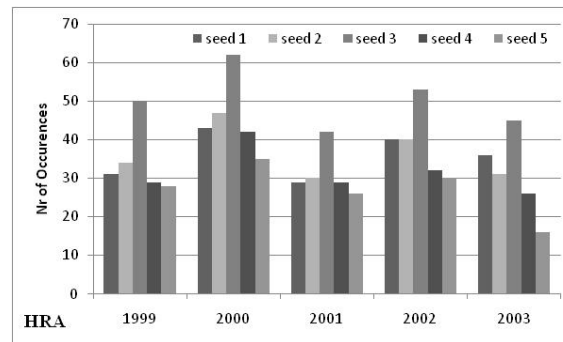
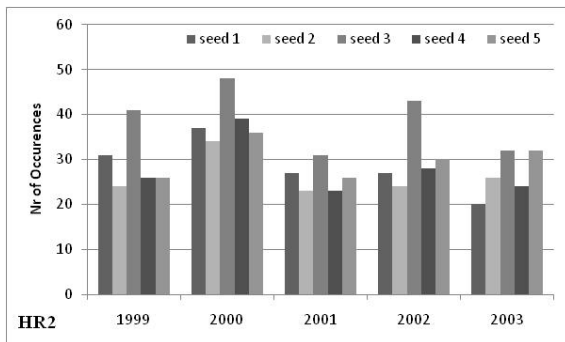
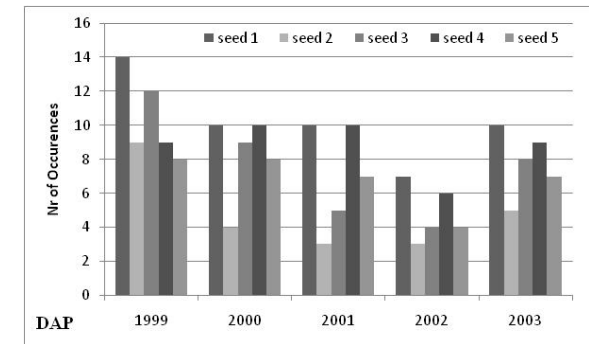
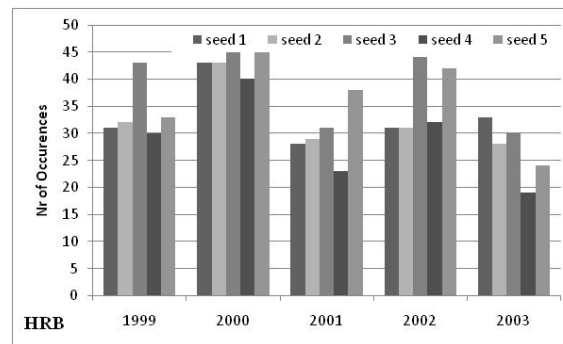
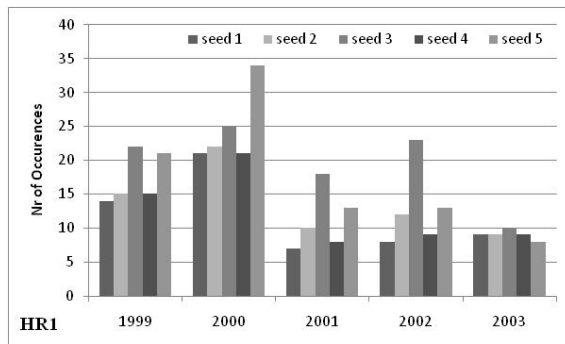
1. Frequency and Duration of Occurrence
2. Lost Energy (capacity factor)
3. Ramp Rates and Reserves Requirements

Simulation results

1. Frequency and Duration of Occurrence
2. Lost Energy (capacity factor)
3. Ramp Rates and Reserves Requirements

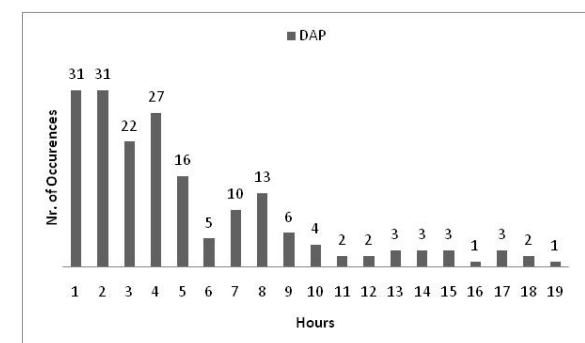
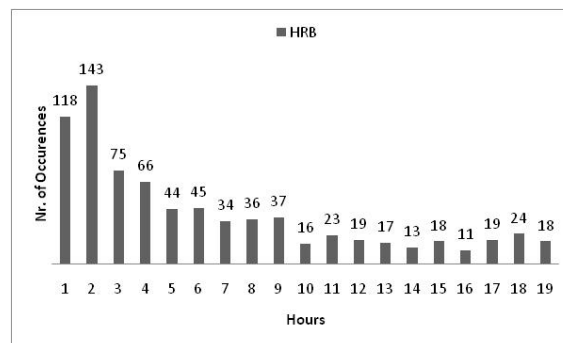
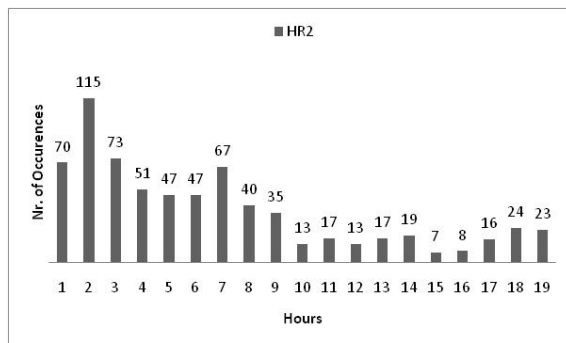
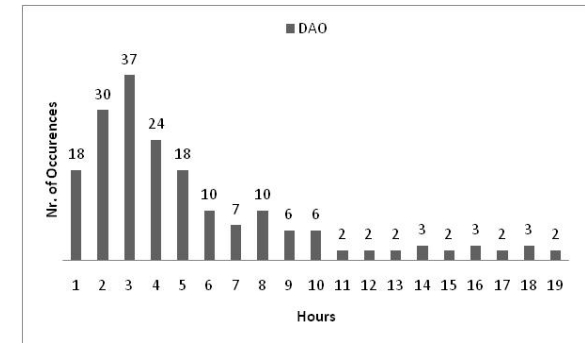
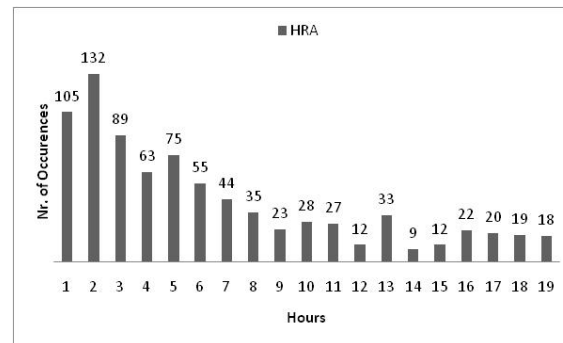
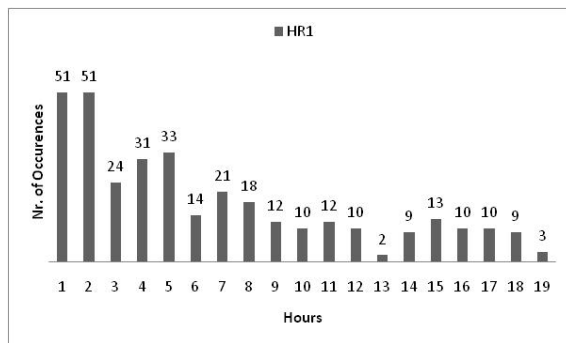
Frequency and Duration of Occurrence

Wind farm level



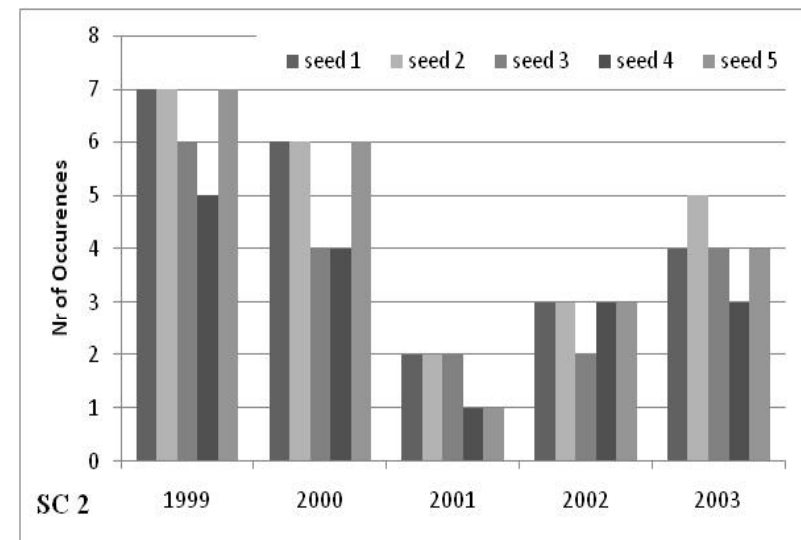
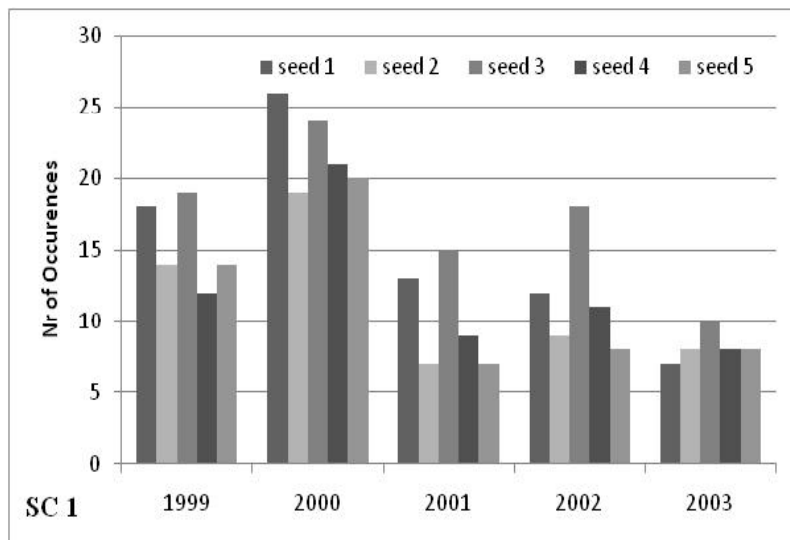
Frequency and Duration of Occurrence

Wind farm level



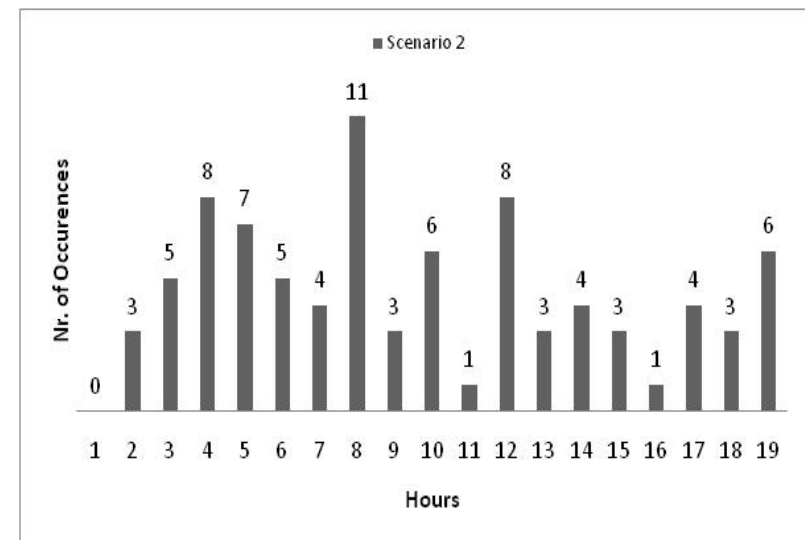
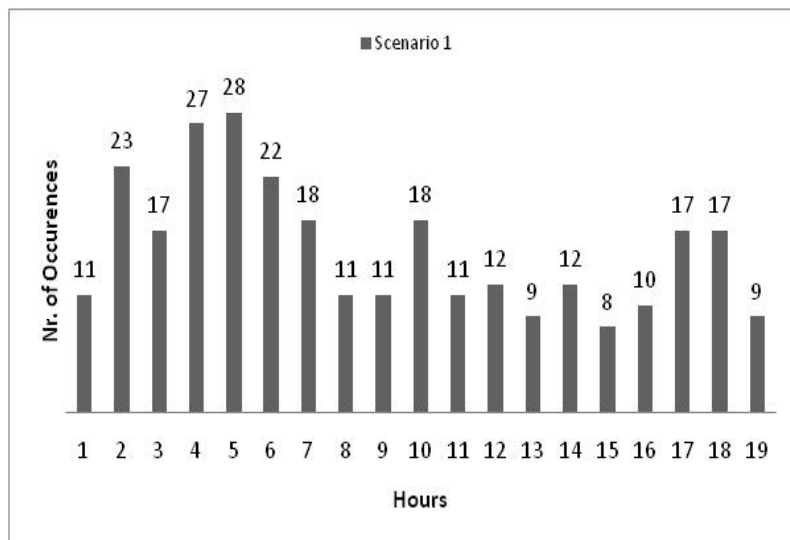
Frequency and Duration of Occurrence

Wind power region level



Frequency and Duration of Occurrence

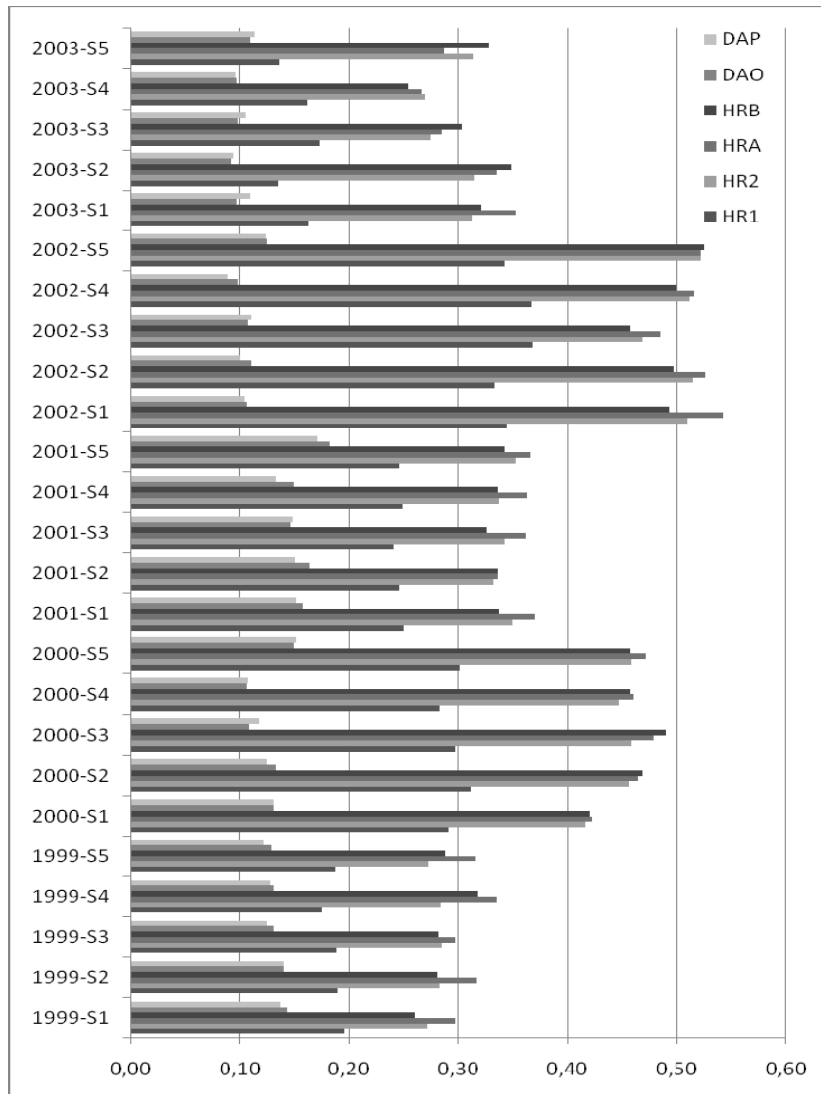
Wind power region level



Simulation results

1. Frequency and Duration of Occurrence
2. Lost Energy (capacity factor)
3. Ramp Rates and Reserves Requirements

Lost Energy – Capacity factor



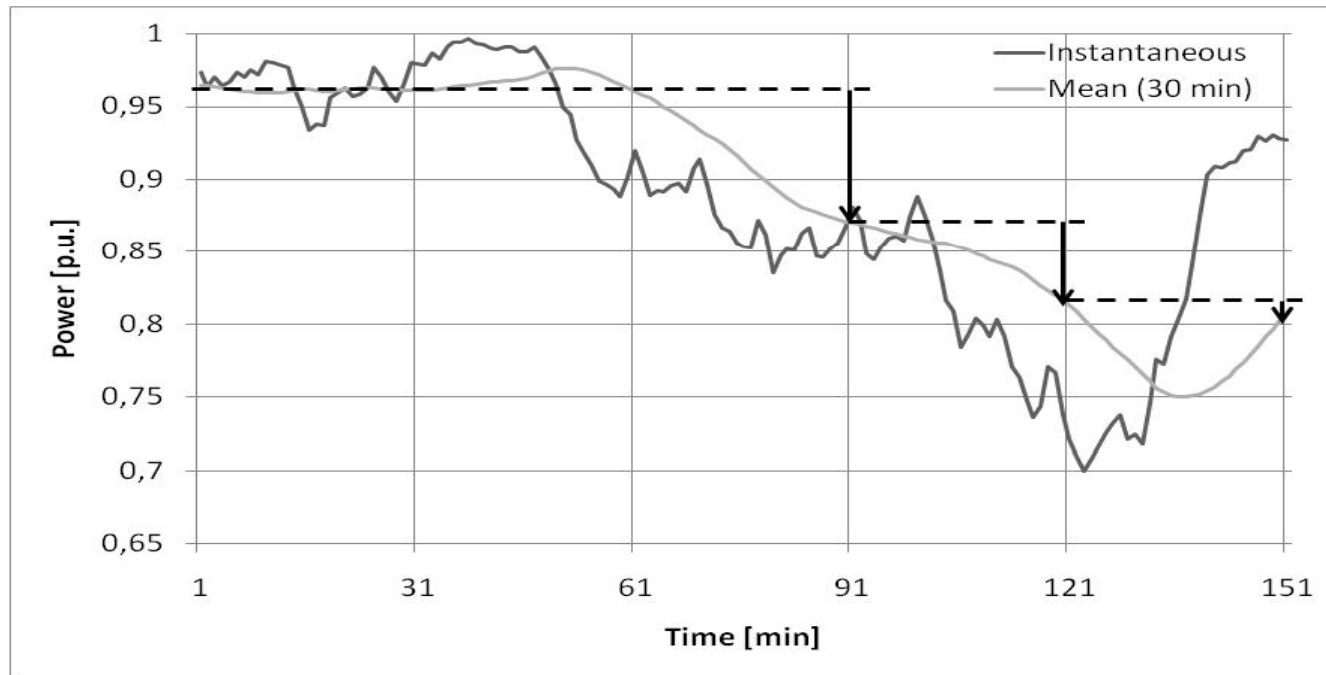
$$C_F = \frac{E_a}{N_h \cdot Cap}$$

Name	HR1	HR2	HRA	HRB	DAO	DAP
Capacity factor difference %	0,25	0,37	0,39	0,38	0,13	0,12
Equivalent full load hours	21,65	32,80	34,26	33,04	11,02	10,81

Simulation results

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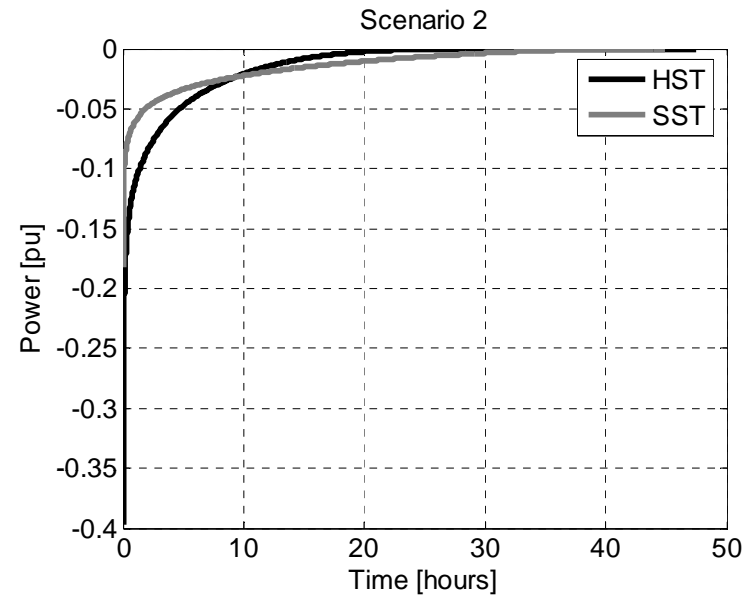
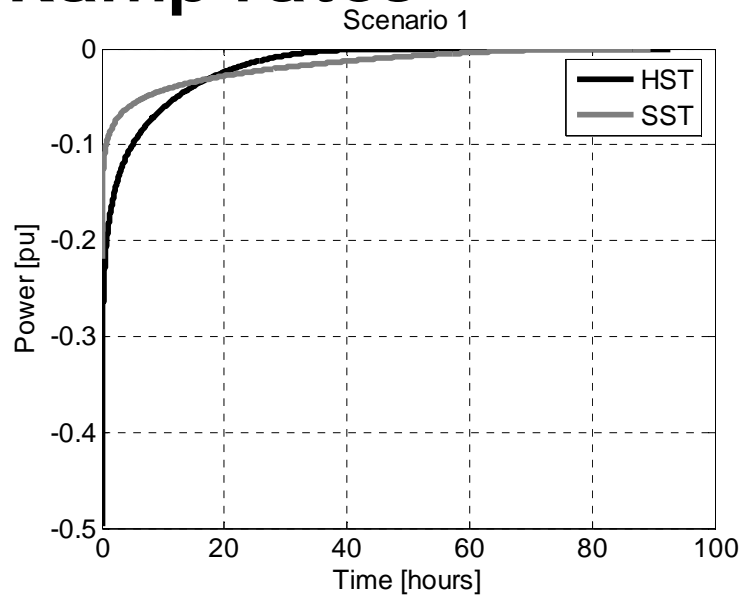
Ramp rates



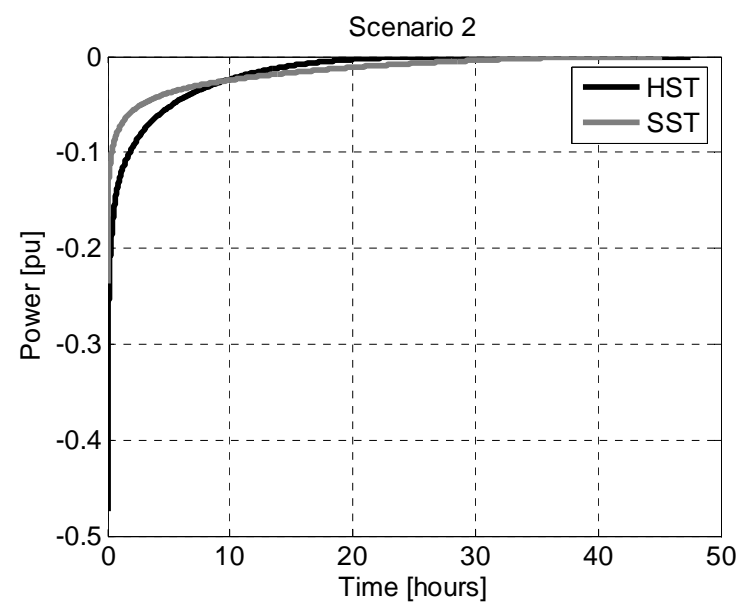
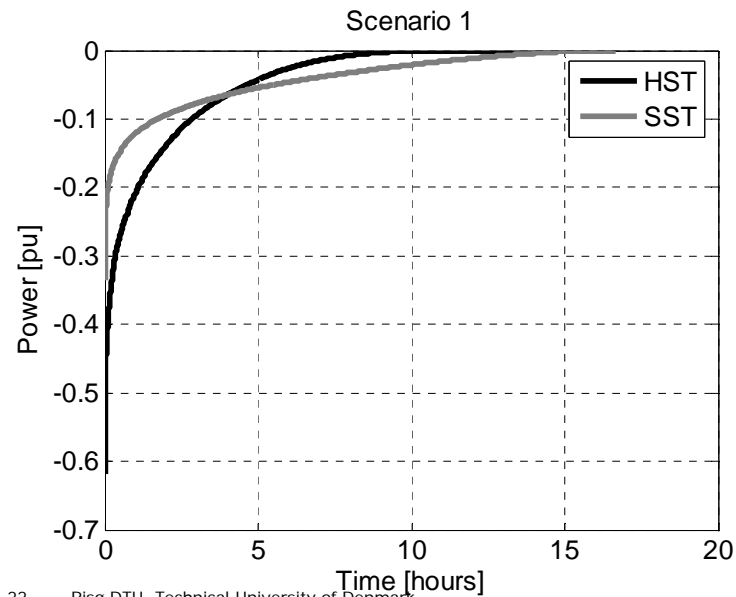
$$P_{\text{ramp}}(n) = P_{\text{mean}}(n+1) - P_{\text{mean}}(n)$$

Ramp rates

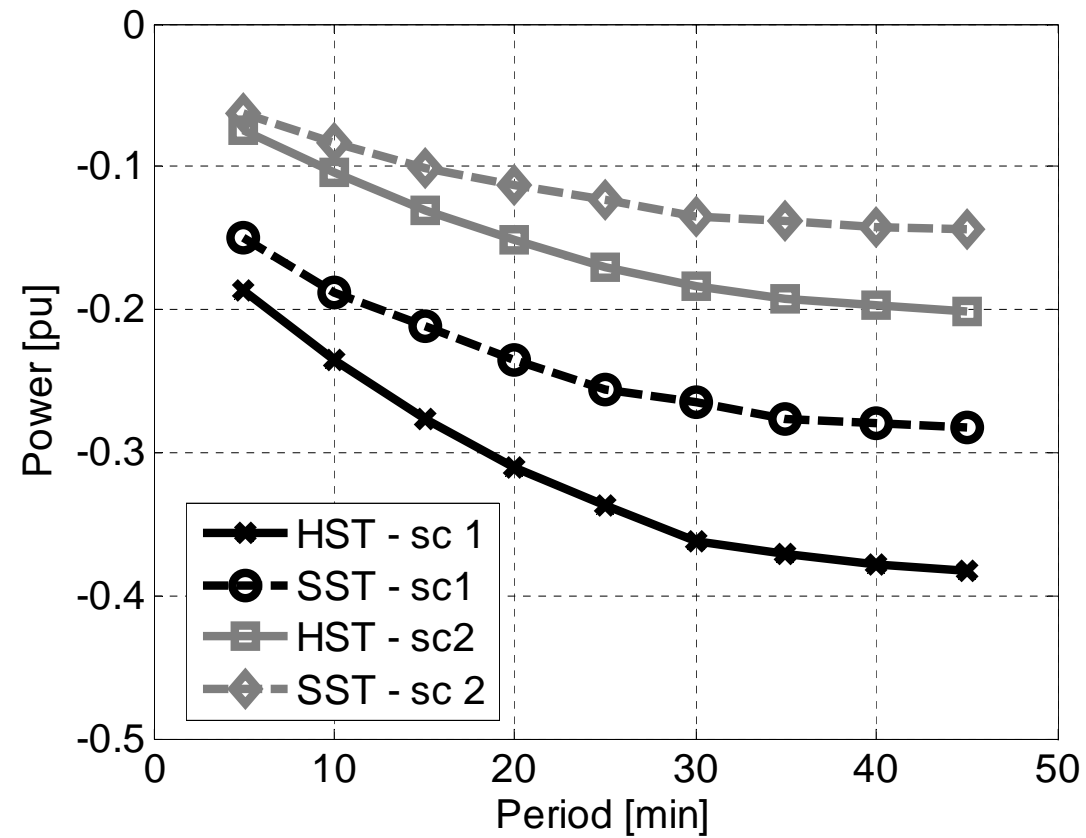
15 min



30 min



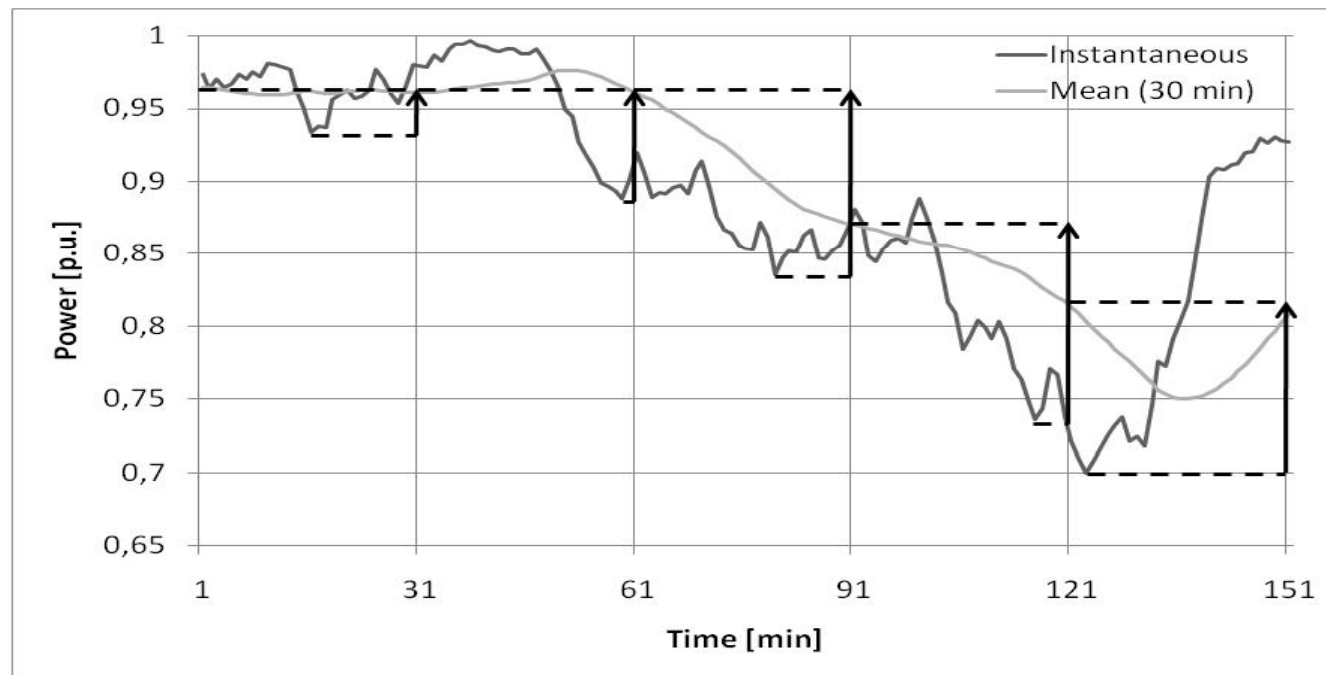
Ramp rates



Simulation results

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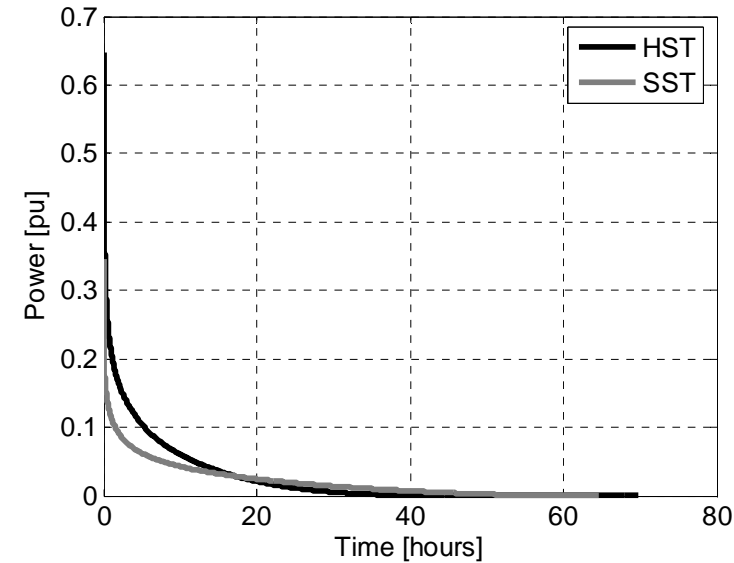
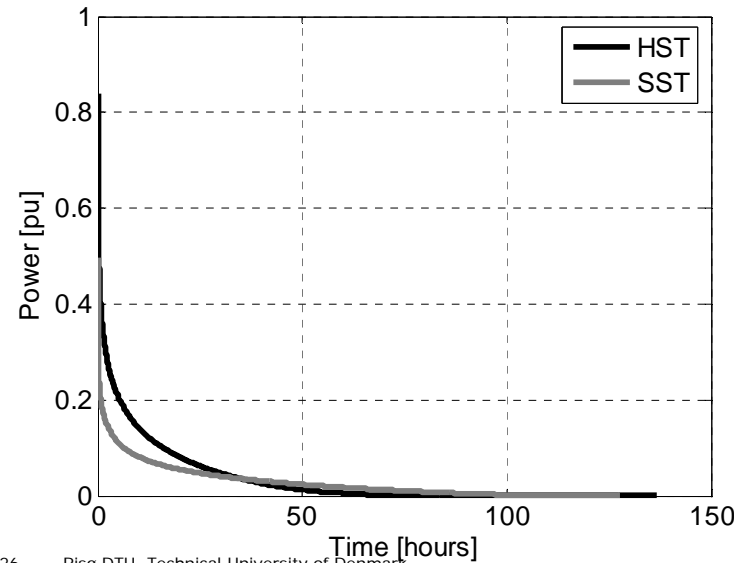
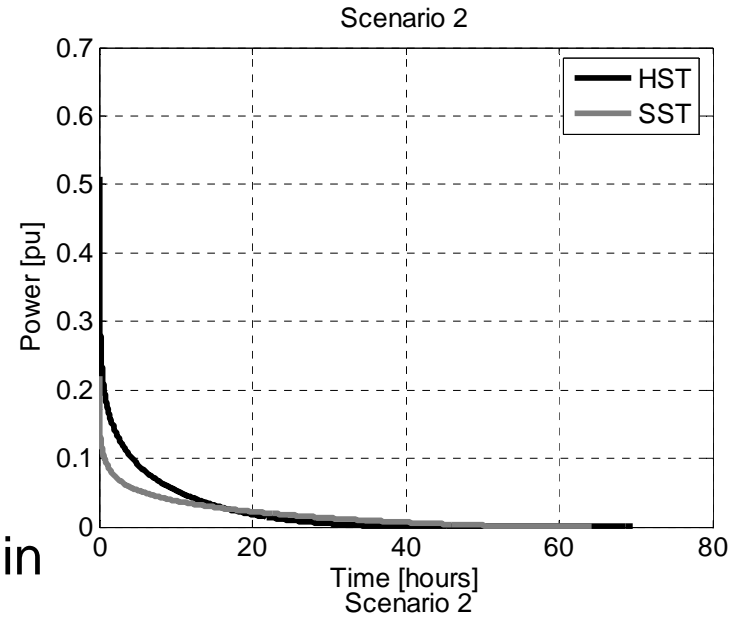
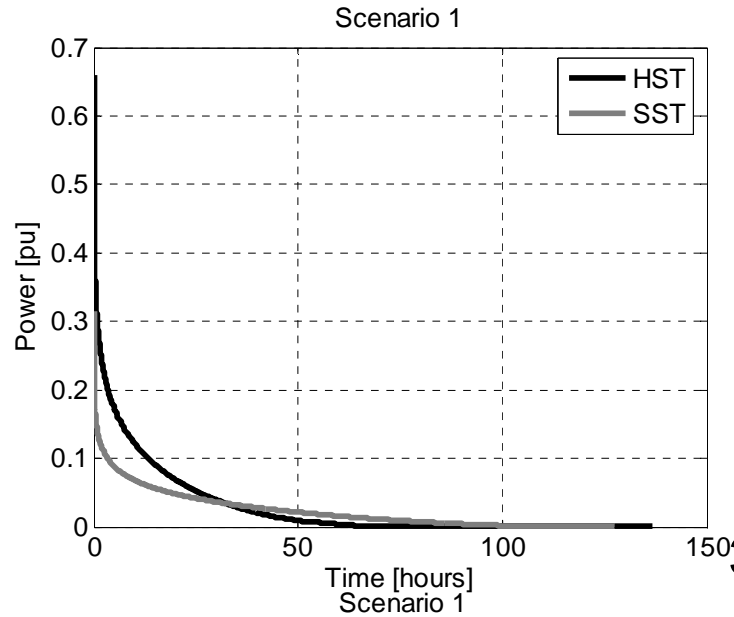
Reserve requirements



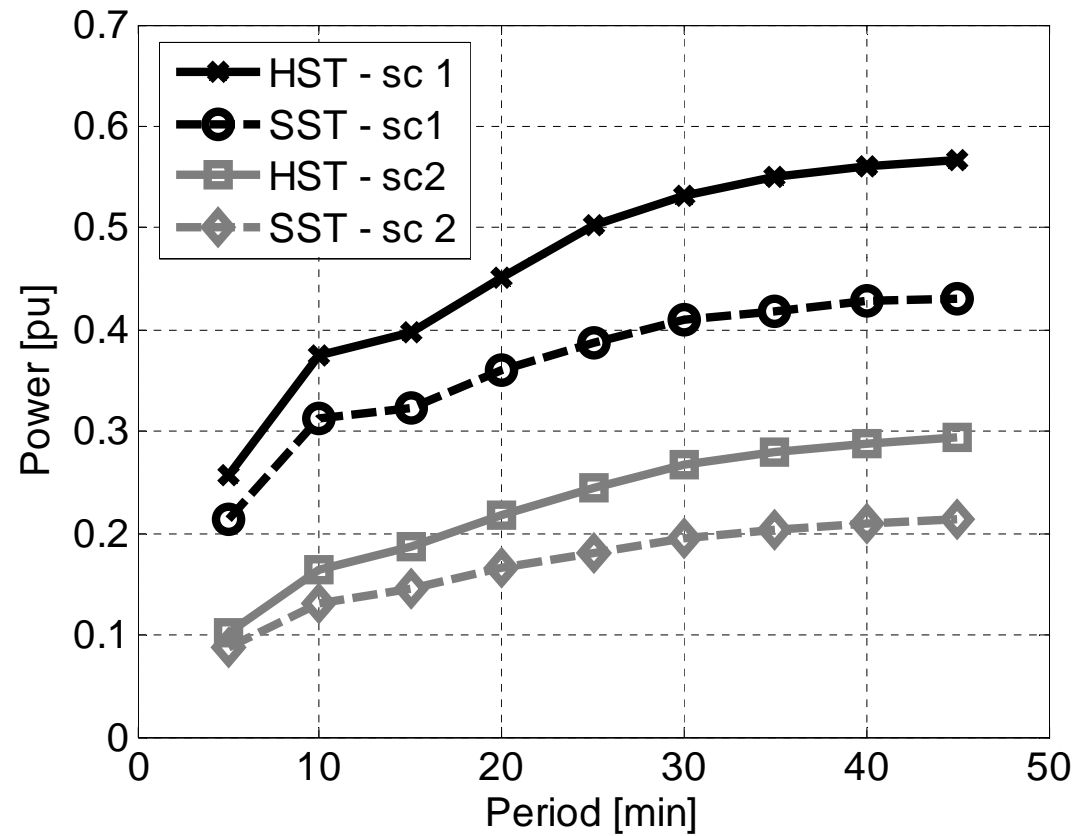
$$P_{\text{reserve}}(n) = P_{\text{mean}}(n) - P_{\text{min}}(n+1)$$

Reserve requirements

15 min



Reserves requirements



Conclusions

- Offshore wind farms operational under extreme wind conditions reliability analysis is important
- Control strategies play a crucial role in increasing the reliability of offshore wind farms power production under extreme wind conditions
- Availability of wind power production at power region level can be improved by proper wind farm location selection